BIO-PHYSICAL COUPLING OF PREDATOR-PREY INTERACTIONS

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Award #: N00014-97-1-0429

LONG-TERM GOAL

Our long term goal is to understand the dynamics of oceanic predator-prey interactions of copepods with feeding currents. Knowledge about the plankton and their oceanic environment will be incorporated into a framework of numerical simulations which includes behavioral aspects and their interactions in conjunction with the other biological processes and physical processes.

SCIENTIFIC OBJECTIVES

Predator-prey interactions and their relative motion cover a wide range of spatial scales. We wish to develop realistic models and simulations that include processes occurring at the relevant scales for a quantitative understanding of the bio-physical coupling in predator-prey interactions.

It is fundamental to understand the physics and the fluid mechanics for predator-prey interactions. At these scales, viscous effects are significant and many of the details of the feeding process are determined by the structure and shape of the organisms involved. Since the Reynolds number of the associated flow is small, it is possible to numerically calculate some of these deterministic aspects. These calculations will augment and extend the direct observations, making it possible to identify the fundamental aspects of the morphology and operation of the predators. Our objective is to understand the biological and physical processes involved in feeding in sufficient detail to quantitatively predict predator-prey contact rates. Such quantitative results will shed light on feeding strategies and rates responsible for the thin layers of high biological concentrations and production now being found in many oceanic environments.

APPROACH

Simulations of the flow, at millimeter scales, have been performed by employing a state-of-the-art, finite-volume code with curvilinear body-fitted coordinates (BFC). This code has the ability to handle complex boundary conditions and smoothly describe the body shape without the jagged edges that would arise with Cartesian coordinates. The feeding current of the copepod is simulated by specifying a force in the water adjacent to the body. Using this code, we obtain details of the feeding current and its interaction with flow non-uniformity. At present the objective is to model the feeding current around a copepod and diagnose the properties of the computed feeding current for comparison with direct observations. We will evaluate forces on the zooplankton due to interaction with externally imposed flow structures.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Bio-physical Coupling of Predator-prey Interactions**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Johns Hopkins University,Department of Earth and Planetary Sciences,3400 N. Charles Street,Baltimore,MD,21218**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Simulations at larger scales will be performed with a code for Large-Eddy Simulation (LES) of high Reynolds number turbulent flow. This code can include stratification. In those calculations the tracking of predators and prey will be based on solving appropriate Ordinary Differential Equations for each "particle". We plan to track large samples of predator and prey trajectories, as they evolve with a three-dimensional unsteady turbulent velocity field.

WORK COMPLETED

Four cases considered to date in order to test the applicability of the code.

1. Stokes flow due to a point force was compared to the exact analytic result for Re=0.008.
2. Stokes flow due to a point force outside a solid sphere was compared to an exact analytic results for Re=0.008.
3. Flow due to a point force outside a solid sphere was calculated for Re=0.8, which is a realistic value for a copepod. No analytical solution is available for comparison with this result.
4. An artificial copepod shape was generated by adding appendages to the sphere in order to have a body that included the antennae and the tail. The feeding current around this artificial "copepod" was calculated for the realistic value of Re=0.8 (Figure 1). This result is compared to case 3 to show the effect of the additional details of body shape.

Having completed the testing of the code and calculated the feeding current around a sphere and an artificial "copepod" we are now performing calculations around realistic shapes for copepods.

RESULTS

In the completed preliminary calculations of the feeding current, we first assumed that a "copepod" was in a shape of sphere, then we added two antennae and one tail to the spherical "copepod" to make an artificial "copepod". Comparing the feeding currents for the two "copepods", we found that with modification of shape from "sphere" to "copepod", the feeding current in front increased and water was drawn in from a greater distance. The more realistic artificial "copepod" would feed from a larger domain than the sphere, showing that the copepod's morphology contributes to its feeding success.

IMPACT

Our work shows that the direct calculation of the feeding current around a copepod is possible. Preliminary calculations on simplified shapes shows that the details of the body shape are important in determining the paths of entrained particles. Computations of the feeding current give details that are difficult to obtain from direct observations. Thus, the calculations expand the value of the laboratory measurements by increasing the spatial and temporal resolution of the role of the feeding currents in the predator-prey interactions.

The study of the oceanic predator-prey interactions, by combining knowledge about plankton and oceanic environment within a framework of numerical simulations, furthers our understanding of the population dynamics in species specific settings. The work shows what is generic about shape, feeding strategy and feeding success.

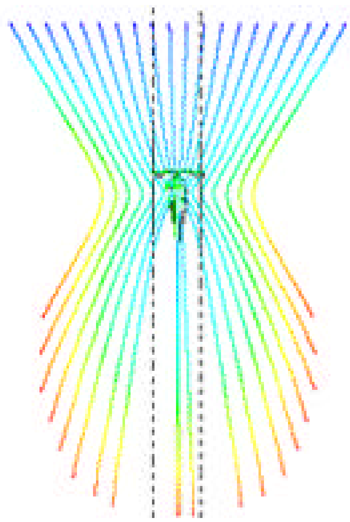

Figure 1. Particle tracks using the computed feeding current around the artificial “copepod”. Twenty particles are tracked. The color indicates the speed with the darkest blue color corresponding to the highest speeds and the darkest red to the lowest speeds.